HARDENING OF ARMORED VEHICLE SUSPENSION COMPONENTS

HUBERT COMMINGE, MR.
US ARMY MOBILITY EQUIPMENT R&D COMMAND
FORT BELVOIR, VA 22060

INTRODUCTION

Mechanically-emplaced and air-delivered land mines have been introduced into the modern battlefield thus compounding the problem of maintaining armored-vehicle mobility. Land mines and mined areas will be encountered by U.S. Forces throughout the battlefield during offensive, defensive, and rear-area support operations. In tracked vehicles, the vulnerable components are those associated with the suspension system and, most particularly, the tracks and roadwheels. This is a critical problem area; a small 3-pound explosive charge can cause a mobility failure on all tracked vehicles. The major damage resulting from such an explosion is the loss of a track section, resulting in an immobile vehicle. Since minefields are usually covered by artillery and anti-tank weapons, an immobilized vehicle can be destroyed quickly.

Historically, warfare scenarios and deployment techniques have limited the use of land mines to certain well-defined situations to impede or channel opposing forces. Advance knowledge of minefield locations could permit effective countermeasures using mine-clearing equipment such as mine-clearing rollers mounted on lead vehicles, projected explosive line charges, or, depending on mine density, bulling through with some sacrifice. The advent of offensive mining through air- and artillery-delivery capabilities has introduced a new tactical situation that requires mobile units to proceed across random-laid minefields or mine areas.

Vulnerability analysis has predicted severe losses of armored combat units in all mine environments. This prompted investigations for providing countermine hardened suspensions for armored vehicles. The following guidelines were developed for hardening tank track shoes and roadwheels thus providing enhanced survivability:

COMMINGE

cont

(1) Suspension components should be hardened to demonstrate enhanced blast survival from the explosion of a undirectional shallow-buried charge.

(2) Hardened components should not exceed the weight of current suspensions.

(3) The M60 tank tracks and roadwheels should be the baseline suspension components.

(4) The vehicle should be mobile after a single encounter and should be able to "limp-off" the minefield and preclude a complete kill ~~(K-Kill)~~.

SUSPENSION FAILURE ANALYSIS

Current tank track shoes and roadwheels are severely damaged when subjected to an explosive charge, even a small (3-pound) track-cutting explosive charge. An analysis was conducted to determine the mode of failure in order to develop the protection mechanism.

In explosive charge-target geometries, where the explosive is in direct mechanical contact with the target, the predominant failure mechanism is shear caused by a large-velocity gradient. This can be illustrated qualitatively by Figure 1.

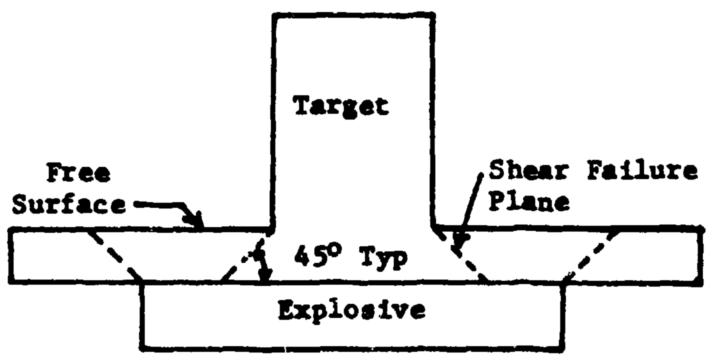

Figure 1. Arbitrary charge/target geometry.

In this arbitrary target, the explosive, simulating an air-scatterable mine, is in direct contact with the target. Detonation of this charge causes a high-pressure shock wave to be propagated into the target material adjacent to the charge. The interface between explosive and target moves upward at a high velocity. Material along the bottom edge of the target, not in direct contact with the explosive charge, receives no velocity wave and, therefore, remains initially at rest. This large velocity

differential between material in contact with and material not in contact with the charge, induces a strong shear stress in the target material. Since the compressive stress is essentially one-dimensional, a shear failure is expected to propagate from the corners of the charge upward along the dashed lines. A similar mechanism also causes shear failure along the dashed lines emanating from the internal corner of the target's top surface. The initial pressure-velocity wave propagates upward until it reaches the free surface; at this time a rare-faction shock reflects from the free surface and imparts a velocity which is approximately twice that of the incident velocity. A velocity gradient exists between the material under the free surface and that where no free surface is encountered; therefore, a shear failure is expected.

Verification that a shear failure can occur around a discontinuity in a target structure is illustrated in Figure 2 below.

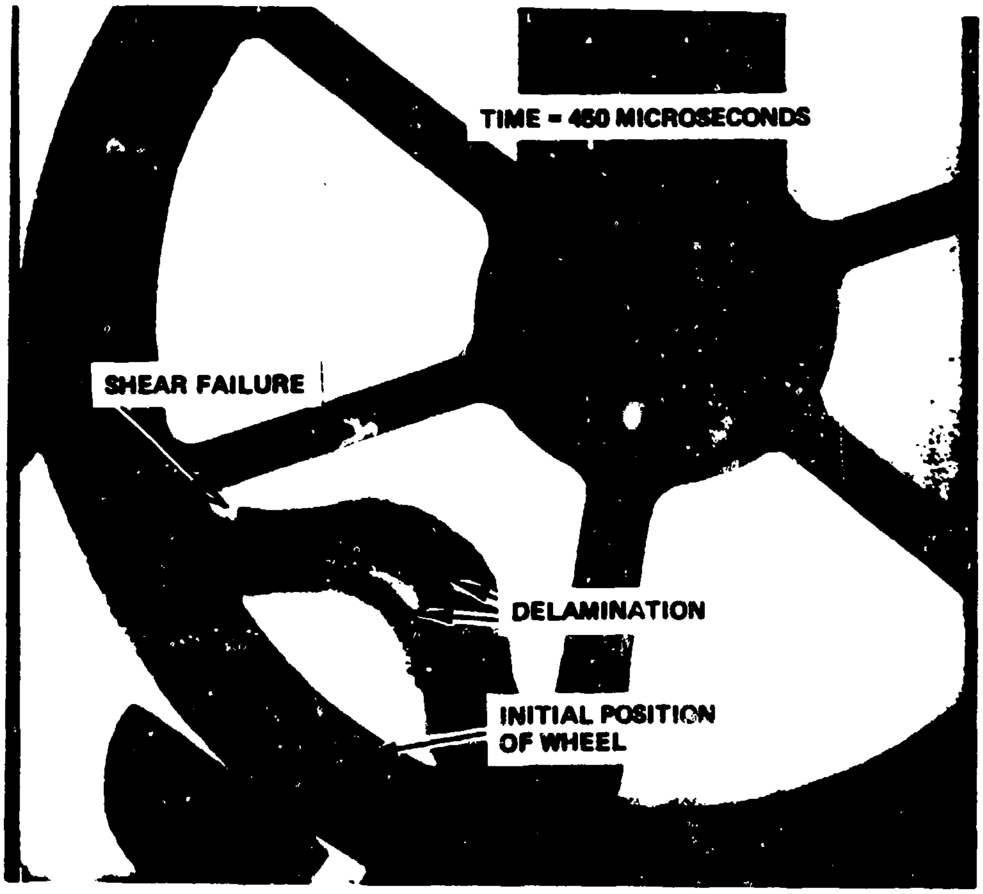

Figure 2. Dynamic X-ray of wheel deformation.

COMMINGE

This doubly exposed radiograph shows a wheel section before and 450 microseconds after initiation of an explosive charge. The wheel was specially constructed for this test and incorporated chosen discontinuities. The wheel rim consisted of weldments of laminated bands and alternating layers of steel and aluminum, with the outermost band being aluminum. The explosive charge, as shown in the radiograph exposure, was placed directly against the wheel to simulate an air-scatterable mine. A shear failure starting from the spoke-rim joint is clearly demonstrated in the 450-microsecond X-ray exposure.

Tests similar to that described above were conducted with different tank roadwheel and track-shoe configurations to locate critical failure points in component structures and to determine how these failures could be controlled or eliminated. Discontinuities within the mine-target environment were the key to component failure. First, almost all observed failures occurred around discontinuities resulting in large-velocity gradients between adjacent portions of material; second, discontinuities that occurred in the structure without inducing a velocity gradient often had the effect of inhibiting failure propagation. In addition, tests demonstrated that reduction of target surface area normal to the explosive blast resulted in a proportional reduction in the overall load delivered to the target structure.

From the roadwheel and track-shoe test results, the protection requirements for tank suspension system survival from landmines were developed as follows:

a. Eliminate sharp geometric discontinuities.

b. Use laminations to inhibit crack propagation.

c. Pre-plan fracture geometry to protect critical tank suspension components.

d. Reduce normal area adjacent to the explosive charge.

e. Use energy-absorbing materials.

f. Incorporate blast deflection in tank roadwheel and track design.

ROADWHEEL AND TRACK DESIGN

The major disadvantages to the current tank roadwheel and track shoe structure, when subjected to a track-cutting explosive charge, are the large flat surface areas presented to the explosive blast source;

in addition, the components contain sharp geometric discontinuities. The large area absorbs the full brunt of the explosive blast and is not conducive to dissipating or deflecting the shock wave. Further, the metal components transmit the large-velocity gradient to other suspension components such as roadarms and torsion bars and cause additional damage.

The new suspension configuration encompasses a single tank roadwheel in lieu of the present dual-roadwheel system and a track shoe having a semi-circular groove for maintaining proper track alignment and interface with the roadwheel. This single roadwheel allows a large amount of the explosive blast to flow by and dissipate quickly; hence decreasing/eliminating the damage to the roadwheel and other suspension components such as the roadarm, shock absorbers, and torsion bars.

The hardened roadwheel internal structure consists of seven fiberglass radial support rings with an outer ring encapsulated in an elastomeric material as shown in Figure 3.

Figure 3. Mine-resistant tank roadwheel.

The support rings are fabricated of E-glass tape bonded with EPON 828 epoxy and Z-modified polyamine; the cure procedure consists of hardening at room temperature and 4 hours at 275°F. The encapsulant is Adiprene APR-882 polyurethane and MOCA-cured.

The mode of deformation for the roadwheel structure uuder load from an explosive blast occurs initially at the single point of tangency between the outer rim and one of the inner rings. As the explosive blast load is applied, both rim and inner ring deform so that the area of mutual contact increases continuously. Since rim-ring contact area increases continuously during loading, structural discontinuity does not occur at a single point and the large-velocity gradient is spread over a wider area minimizing and/or eliminating structural damage depending upon explosive charge size.

The hardened track shoe was developed to provide the required structual integrity, proper floatation, and minimum area of primary structure adjacent to the explosive blast. The shoe consists of two metallic links with accommodating pins and bushings, a metallic yoke, and a non-metallic track-shoe body as shown in Figure 4.

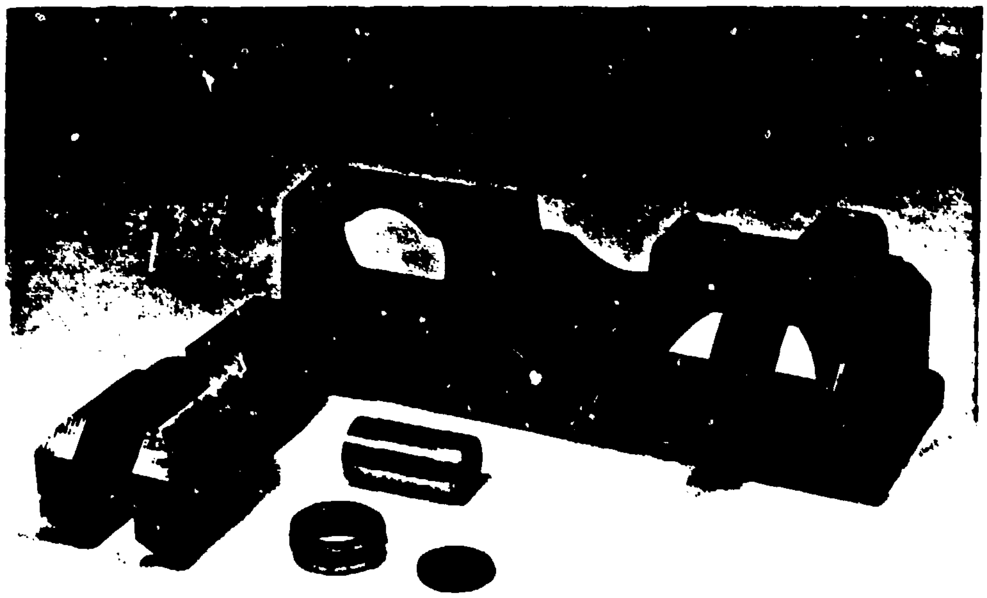

Figure 4. Mine-resistant tank track shoe.

The links, yoke, and pins manufactured of 4340 steel and hardened to a Rockwell C43 provide necessary structural integrity for both mobility and explosive blast and are configured to minimize the area of primary structure. The primary purpose of the yoke, besides adding to the structural integrity of the track shoe, is to eliminate the latitudinal separation of the track links under explosive blast. Earlier testing of hardened track shoes without yokes resulted in the breaking of large numbers of non-metallic track-shoe bodies because of excessive longitudinal and latitudinal motions of the track when subjected to an explosive blast. The track-shoe body consisting of Adiprene L-315 (Shore D-70) molded to the yoke, provides the necessary vehicle floatation and traction and is sacrificed during the explosive blast; this loss allows for quicker dissipation and/or venting of the shock wave. The track-shoe design is such that the links are inserted sideways into the opening of the yoke and rotated 90 degrees to lock in place; this design eliminates the currently used track-shoe end connectors and accessories. Further, the center guides are completely eliminated; track guidance is achieved by the semi-circular groove of the track shoe body that allows better wheel traversing for terrain contour.

ENERGY ABSORBING MATERIALS

Detonation of a landmine releases a large quantity of energy in a very short period of time, creating a large moment of inertia on the track and roadwheel subsystem. Prior to destruction, the roadwheel imparts a moment to the roadarm assembly which is transmitted to the torsion bar, causing catastrophic failure of these components. In addition, a large antitank mine containing 15 pounds or more of explosive will remove the torsion bar housing from the tank hull. Materials, other than metals, capable of absorbing some of the explosive energy were required to decrease the overall transmitted inertia and decrease suspension component destruction.

Different energy-absorbing materials were analyzed; the most promising material compositions were subjected to explosive blast tests. It was obvious that full-scale explosive testing of all promising energy-absorbing materials and design configurations would be prohibitive; therefore, a low-cost testing procedure was developed to eliminate undesirable composite materials. The testing was accomplished by fastening the energy-absorbing material to a rigid I-beam with one end pinned to a concrete foundation (as shown in Figure 5). The beam was free to rotate about its pin joint, and rotation was measured by means of a mechanical scribe. Beam mass and moment of inertia were determined prior to each test so that energy collected by the composite material sample and transmitted to the beam could be calculated from measured beam

rotation. A baseline material was required to compare the energy dissipated or absorbed by each composite material sample; steel was chosen as the baseline material, with the assumption that it would not absorb and transmit the energy directly to the beam.

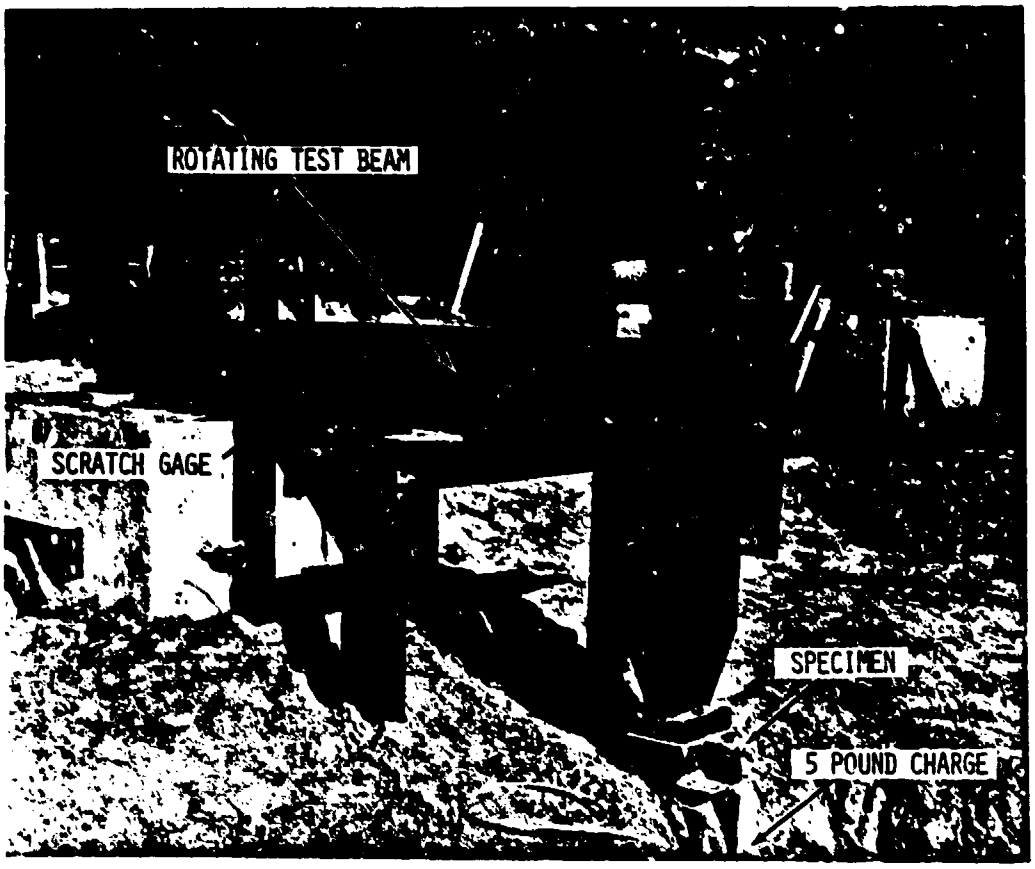

Figure 5. Energy absorption test set-up.

The table gives a partial listing of composite materials tested for the tank track shoe. The vehicle must be capable of traveling after a mine detonation; therefore, the composite material should dissipate 100 percent of the energy to eliminate damage to other suspension components and yet remain intact to allow for vehicle floatation. For this reason, the composite materials having the highest percentage value of energy dissipated with the least damage were employed in full-scale testing on a combat tank.

COMMINGE

Results of Energy Tests of Track Composite Materials

	MATERIAL	ENERGY DISSIPATED (%)	DESCRIPTION OF BLAST DAMAGE
THERMOSETTING	Epoxy-Epon 828/Catalyst Y	60	Partially fragmented
	Urethane-Uralite 3121S	18	Minimal
	Epoxy-Epon 828/Catalyst Y, Silica-Reinforced	53	Partially fragmented
	Epoxy-Epon 828/Catalyst Y, Steel-Reinforced	58	Fragmented
	Non Rigid Epoxy-Epon 282/DDSA	61	Fragmented
	Polyster-Glass-Reinforced	54	Pulverized
	Epoxy-25% Keular-¼ inch	64	Partially fragmented
THERMO-PLASTIC	High-Density Polyethylene	64	Eroded
	Polycarbonate--Unfilled	59	Minimal
	Polycarbonate--40% Glass Fibers	63	Fragmented
	Polyurethane--40% Glass Fibers	59	Partially fragmented
	Steel	0	Totally Destroyed

EXPLOSIVE TESTS

Both the present dual-roadwheel tank suspension and single-roadwheel hardened suspension systems were subjected to numerous full-scale explosive tests. Tests were conducted with operational and simulated landmines containing 5, 13, and 22 pounds of explosive. Most foreign landmines contain cast TNT; therefore, all simulated explosive charges were fabricated with TNT.

The 5 pound explosive charge, simulating an air-scatterable mine, was placed in direct contact with the tank track as would occur in an operational situation. The present dual-roadwheel suspension system sustained the following major damage, causing a mobility kill:

a. Dual roadwheel completely demolished, whether steel or aluminum.

b. Two track shoes completely destroyed.

c. Broken torsion bar at the first station.

d. Broken adjusting link at roadarm connection.

COMMINGE

The damage sustained by the hardened suspension from the same explosive charge was negligible, clearly demonstrating the energy absorption of the chosen materials. As a matter of fact, the tank continued its mobility mission without degradation. The damage was:

a. Loss of two or three track shoe plastic bodies (designed to be sacrificed during explosion).

b. Very slight cracking/peeling of roadwheel encapsulant.

The next phase of testing was conducted to determine damage from off-the-shelf antitank mines. The explosive charge contained 12.6 pounds of cast TNT and was encased to simulate typical Warsaw Pact landmines. The simulated mines were covered with 2 inches of soil. The dual-roadwheel suspension consisted of steel roadwheels and T-142 track. The damage from the explosive blast is shown in Figure 6.

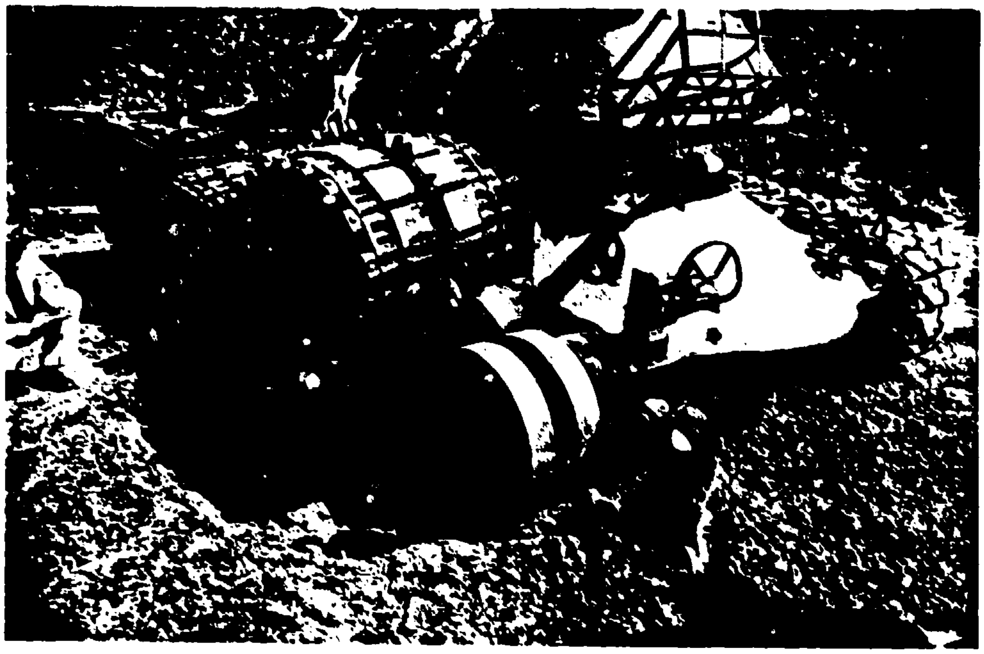

Figure 6. Damage to present suspension system from 12.6 pounds of TNT.

The damage, as shown above, was extensive and resulted in a mobility kill as follows:

a. Complete destruction of three track shoes.

b. Complete removal of the first dual roadwheel from the spindle (the wheels were sufficiently damaged to prohibit reuse).

COMMINGE

c. Broken torsion bar at the first station.

d. Broken adjusting link.

e. Loosening of first and second stations torsion-bar housing caused by hull mounting-bolt shear.

f. Removal of roadarm from housing and rotating forward of vehicle.

The following damage to the hardened suspension (Figure 7) was much less severe and did not result in a mobility kill:

a. Cracking of the roadwheel encapsulant.

b. Loss of three track-shoe plastic bodies (designed to be sacrificed during explosion).

c. Loosening of adjusting link.

d. Loosening of first-station torsion-bar housing.

Loosening of the idler-wheel adjusting link eliminated the track tension, but since the track links remained undamaged, the vehicle was able to proceed under its own power with mobility degradation.

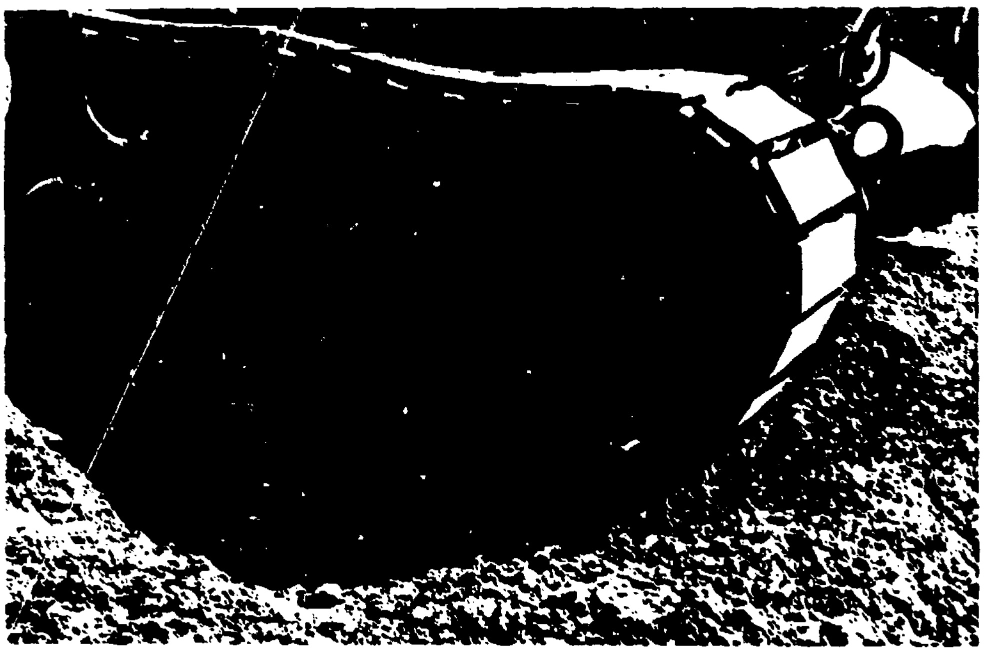

Figure 7. Damage to hardened suspension system from 12.6 pounds of TNT.

COMMINGE

The final phase of testing was conducted using 22 pounds of explosive; this equates to the largest off-the-shelf antitank mines. The present dual-roadwheel suspension system was not tested because the damages would have been greater than previously encountered with the smaller explosive charges. The hardened suspension suffered a large amount of damage, but not sufficient to cause a mobility kill. The damage was as follows:

a. Roadwheel encapsulant is seriously damaged and inner ring structure is slightly cracked.

b. Loss of 6 to 8 track-shoe plastic bodies.

c. Loosening of adjusting link.

d. Breakage of 3 to 4 track-shoe steel yokes.

e. Loosening of both the roadarm and torsion-bar housing caused by shear of mounting bolts.

Mobility was greatly reduced, but the vehicle still proceeded under its own power. The track metal links and pins were not damaged and could engage the tank drive sprocket.

CONCLUSION

The goal of the hardening program was to demonstrate that damages to tank suspension systems from the detonation of a landmine could be minimized and, thus, decrease mobility kills. Through redesign and judicious material selection, a new suspension concept was developed and demonstrated successfully, thus eliminating armored vehicle mobility kills and allowing the vehicle to continue its intended mission or to be repaired for the next battle.